SCIENCE FOR CERAMIC PRODUCTION

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CERAMICS FOR MOTOR BUILDING

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Simples method for fabricating inexpensive ceramic fibers suitable for reinforcing metal and manufacturing high-porosity ceramic parts with a fiber structure for service in the bottom of ICE pistons are described.

The practical solution of the problem of creating composite materials in a fiber-metal system is connected with the development of a simple technology for manufacturing fibers suitable for reinforcing metals. The properties used to estimate the suitability of fibers for this purpose can be divided into three groups, namely,

– physicochemical properties that determine compatibility with the metal;

– mechanical properties that determine the possibilities of reinforcing the metal;

– economic factors that determine the practical possibility of realization of large-scale production of fibers and articles from them.

Taking these conditions into account we can limit markedly the range of appropriate fibers to inorganic nonmetallic materials that can be divided into three groups, namely, whisker single crystals, polycrystalline fibers, and amorphous fibers.

Whisker single crystals can be obtained from virtually any element and compound. The physicochemical properties of single crystals do not differ from those of bulk materials but have mechanical properties superior to virtually all known materials and approach the theoretical strength of a crystal bond. Whisker single crystals are inert with respect to most of the metals and possess high ultimate tensile strength (2100 – 8300 MPa) and modulus of elasticity (470 – 550 GPa) [1]. At the same time, large-scale production of such single crystals has not yet been organized in Russia.

Polycrystalline fibers possess physicochemical properties comparable with those of metals. Their mechanical properties are inferior to those of whisker single crystals but are still quite suitable for reinforcing metals [2]. However, large-scale production of such fibers has not started in Russia.

Fibers with an amorphous structure have been developed and produced in the form of heat-insulating and heat-protecting materials.

Mineral wool materials are represented by fibers with the chemical composition $x\mathrm{RO} \cdot y\mathrm{Al_2O_3} \cdot z\mathrm{SiO_2}$. The initial temperature of their softening is less than 600°C and the mechanical properties are rather low [3]. For this reason, their use for reinforcing metals is problematic.

Glass fibers of mullite-silica composition are inert with respect to metals and their melts. Their mechanical properties are satisfactory for reinforcing metals (the ultimate tensile strength is 1400 MPa, the modulus of elasticity is 150 GPa) [4]. Russia possesses successfully functioning plants producing such fibers.

In fact, the mentioned kinds of fiber exhaust the materials suitable for reinforcing metals.

Thus, glass fibers of mullite-siliceous composition are the best candidates of all the existing and available fiber materials for reinforcing metals (with respect to the physicochemical and mechanical properties, the availability, and the price).

However, the produced material possesses a substantial disadvantage. The method of its production is such that its composition is represented by both fiber and nonfiber ingredients. The GOST 23619–79 standard permits the presence of nonfiber particles 0.5 mm in size in an amount of up to 3%. This does not affect noticeably the thermophysical properties of the material but the presence of a nonfiber component in compositions with metal is impermissible.

Therefore, it has become necessary to develop a simple technology for fabricating fibers using the available equipment; the process parameters should be variable in a wide range without worsening noticeably the quality and yield of the final product.

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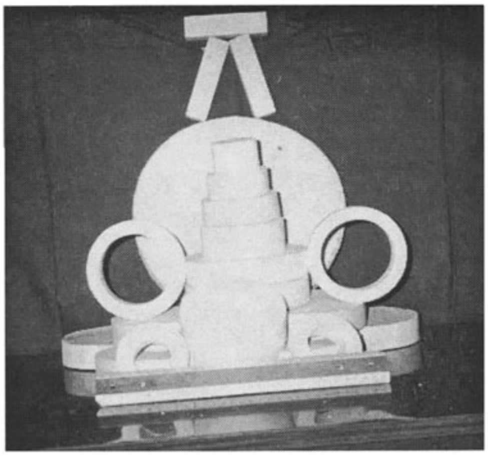

Fig. 1. Highly porous ceramic parts.

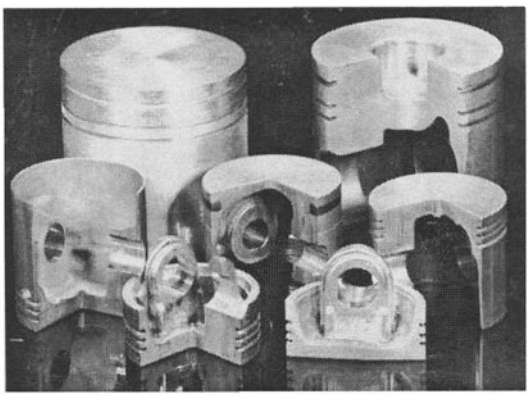

Fig. 2. Specimens of pistons with reinforced bottom.

A technology for separating pure fibers from the initial material has been developed. The content of retained globules in the fiber is at most 1% at a diameter of less than 10 μm.

The equipment for realizing the process is so simple that the nonstandard bay for enriching the fibers has been produced in a conventional mechanical shop.

The process is easy to control; even unprepared people who study the whole process for one day are ready to fabricate the final product independently.

The obtained fibers are suitable for reinforcing aluminum, copper, and iron-base metals, which means that it is possible to create a wide spectrum of structural materials for various purposes.

The search for the fields of application of the developed fibers has shown that it can be used for design and manufacture of pistons of internal combustion engines (ICE) with reinforced bottom. Therefore, we had to solve the problem of compatibility of the fibers and the piston aluminum alloy and development of an appropriate composition for ICE pistons. At the present time metallic pistons are produced predominantly from melt. Therefore, we searched for a liquid-phase method for fabricating the composition.

The main problem in making the fibers and the molten metal compatible consisted in overcoming the poor wetting of the surface of the mullite-silica fibers by the melt (the wetting angle is about 150°). We assumed that the most rational way for solving this problem consists in impregnating the porous ceramic part fabricated from the fibers with molten metal under pressure.

This required the development of a simple technology for fabricating parts from fibers that would possess a high porosity and an appropriate mechanical strength. The volume content of the fibers in the composite should be 10% and the porosity of the part should be 90%. At such a porosity the pore size in the ceramic material should be 5 – 6 μm. Pores of this size are filled at a wetting angle of 150° at a pressure of 0.3 MPa.

The requirements to the technology were chosen as in the process of enriching the fibers, i.e., the processes, the equipment, and the raw materials should be simple and available.

Such a technology has been invented and realized. The nonstandard equipment has been produced by a conventional shop and people without special preparation can master the process of production of the parts during one production cycle.

The technology makes it possible to fabricate parts with a wide range of porosity (75 – 92%) and a sufficiently high mechanical strength (0.5 – 0.6 MPa). The parts can be fabricated in the form of prisms, rings, and plane and shaped disks up to 300 mm in diameter (Fig. 1).

A composition in the fiber – metal system is obtained by way of filling the pore space of a ceramic part with a fiber structure with molten metal and subsequent cooling. The most promising technique for realizing the process involves pressure casting and crystallization of molten metal.

This technique makes it possible to produce a composition in a fiber – metal system and fabricate parts from it in a single process. A preform of an ICE piston with a fiber-reinforced bottom is presented in Fig. 2.

Mechanical treatment of the composition by a blade differs little from the treatment of the alloy. The true density of the composition is virtually similar to that of the alloy and amounts to 2.73 g/cm^3. The TCLE of the composition is 10% lower than that of the alloy.

The ultimate tensile strength of the obtained material has been measured in the range 20 – 350°C. Without taking special measures the ultimate strengths of the alloy and the compositions at 20°C are the same, but with the increase in the temperature the ultimate strength of the composition increases, attaining 120 and 80 MPa at 350°C, respectively.

The time before failure of a specimen was determined under a load of 35 MPa and a temperature of 350°C. For the alloy it is 5 – 7 h, and for the composition it is an order of magnitude longer. Some composite specimens failed after more than 150 h.

The hardness of the composition and of the alloy at 20°C is 130 and 100 *HB*, respectively.

The heat resistance of the materials was determined by comparing the thermal shock resistance of the combustion chamber of a commercial piston and the resistance of a similar part from the developed material. The first crack appeared in the commercial piston at the 2000th cycle. On the composite piston a crack appeared after 12,000 cycles.

Thus, we have developed a simple technology that makes it possible to produce a composite material in the fiber – metal system and a part from it (a preform of ICE piston) in one process.

The technology provides quite competitive products.

Pistons with bottom reinforced by the suggested fibers have been tested in a VAZ car that participated in the all-Russian race in January 2000 (Dmitrov). It should be noted that this car won the race.

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